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RESEARCH DEPARTMENT

REPORT

COLOUR CAMERAS:
Automatic compensation for changes in the spectrum of the light incident on to the scene

No. 1970/15

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

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SUMMARY

Prototype equipment is described which automatically corrects the colour balance of a colour television camera for changes in the scene illuminant.** The performance of this equipment, which is assessed over a wide range of illuminants, shows that a satisfactory degree of automatic control may be obtained in practice.*

1. INTRODUCTION

In present-day colour television practice the scene illuminant is allowed for by equalizing the outputs of the camera channels ('balancing'), using an accurately neutral grey-scale placed in the scene. This process ensures that achromatic objects in the scene are reproduced with the same chromaticity as that of the 'reference white' to which the reproducing display is adjusted. In some circumstances (Outside Broadcast operations in particular) widely varying scene illuminants may be encountered; these variations may be functions of both time and camera orientation. Under such conditions it could be an advantage to correct automatically for the change of illuminant and thus eliminate the appearance of colour casts in the received picture without the necessity of repeatedly using the neutral grey-scale. Such correction would be required irrespective of the absolute magnitude of the illumination intensity, which can vary over a range of about three decades, and ideally the equipment providing the automatic correction for change of illuminant should function over this intensity range without manual intervention.

* This equipment has been described by the acronym ACCIS (Automatic Compensation for Change in Illuminant Spectrum).

** The term 'illuminant' is used to denote the spectrum (relative power per unit wavelength range) of the radiation falling on to the scene, exclusive of the absolute intensity of this radiation.

2. GENERAL PRINCIPLES OF OPERATION[1]

In a colour television camera an equal adjustment of the sensitivities of all signal channels is provided by control of the camera exposure (the lens iris, for example) while the sensitivity of individual channels may be adjusted by controlling the gains of amplifiers in each channel. Sufficient degrees of freedom in sensitivity adjustment are therefore available for colour balancing purposes if the gain of one 'reference' channel is regarded as fixed and the gains of the other 'controlled' channels are adjusted. Consider the situation in which a colour camera is exposed to a grey-scale, while a set of photoelectric receptors contained in an 'illuminant sensing head' are simultaneously exposed to the scene illumination. The electrical output of each of these photoreceptors is proportional to the intensity of incident illumination, and each photoreceptor has a spectral characteristic identical with one signal channel of the camera. Initially, in the presence of a defined illuminant, the camera iris control and video gain controls are adjusted for correct and equal video signal magnitudes, while the photoreceptor sensitivities in the illuminant sensing head are also adjusted so that equal photoreceptor signal outputs are obtained. A subsequent change in the illuminant will alter the ratios between the linear camera video-signal magnitudes and the ratios between the corresponding photoreceptor signal magnitudes to exactly the same extent. These latter ratios therefore provide a measure of the extent to which the camera colour balance has been affected by the change in illuminant, and automatic compensation for this spectrum change can be achieved if this information can be used to re-adjust the camera video gains by the appropriate amount. This result may be

achieved by using the arrangement shown in Fig. 1,* in which photoreceptor A is the 'reference' photoreceptor (that is, it has a spectral response identical to the reference channel in the colour camera) while photoreceptor B has a spectral response corresponding to one of the controlled colour camera channels. The output signals from both photoreceptors are applied to a subtracting circuit, a variable-gain amplifier being interposed between photoreceptor B and this circuit. The output of the subtracting circuit constitutes an error signal and is used to control the gain of the variable-gain amplifier. An identical variable-gain amplifier, also controlled by this error signal, is included in the linear-signal path of the appropriate colour camera channel (that is, the channel whose spectral characteristic has been reproduced in receptor B).

Let E_A be the signal from receptor A

E_B be the signal from receptor B

E_x be the signal at the output of the variable gain amplifier associated with receptor B

ΔE be the output of the subtractor circuit (error signal)

μ be the gain of the variable-gain amplifier associated with receptor B.

It can be seen that:

$$\Delta E = E_A - E_x \tag{1}$$

$$\text{and} \quad E_x = \mu E_B \tag{2}$$

$$\text{Thus } \Delta E = E_A - \mu E_B \tag{3}$$

$$\text{Let} \quad \mu = \mu_0 + \frac{\mu_E}{E} \cdot \Delta E \tag{4}$$

where μ_0 is a constant gain factor and $\frac{\mu_E}{E}$ is a factor relating to the sensitivity of the variable-gain property of the amplifier (it is expressed in this quotient form to preserve the dimensional integrity of the equation). Then from (1), (2), and (4)

$$E_x = E_B \left[\mu_0 + \frac{\mu_E}{E} (E_A - E_x) \right]$$

$$\text{or } \frac{E_x}{E_B} = \mu = \frac{\mu_0 + \frac{\mu_E}{E} E_A}{1 + \frac{\mu_E}{E} E_B} \tag{5}$$

* In this and subsequent figures full lines are used to denote main signal paths and dotted lines to denote control signal paths.

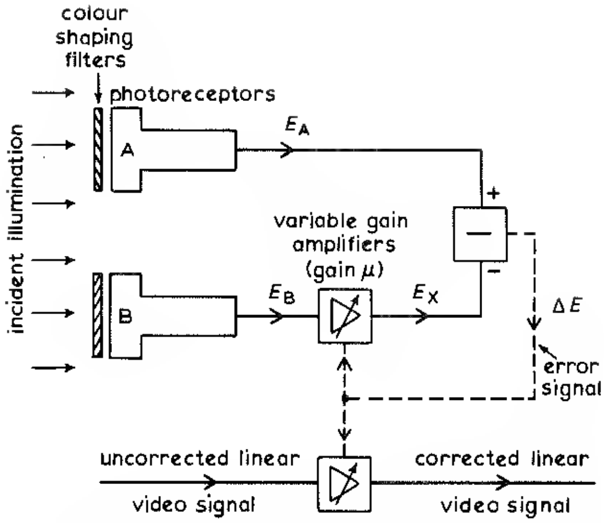

Fig. 1 - Basic arrangement for automatic compensation for changes in the scene illuminant

Now when $E_A = E_B$, $\mu = 1$ since no gain correction is then required. Hence $\mu_0 = 1$ and equation (5) becomes

$$\mu = \frac{1 + \frac{\mu_E}{E} E_A}{1 + \frac{\mu_E}{E} E_B} \tag{6}$$

If $\frac{\mu_E}{E} . E_A \gg 1$ and $\frac{\mu_E}{E} . E_B \gg 1$, equation (6) reduces to

$$\mu = \frac{E_A}{E_B} \tag{7}$$

Since the two variable-gain amplifiers in Fig. 1 are identical and are controlled by the same error signal, the gain of the amplifier in the video-signal path is also given by Equation 7. Because of the previously discussed identity of the photoreceptor-signal ratios and the corresponding video-signal ratios (assuming an achromatic scene) this gain is the value required for restoration of the correct colour balance to the camera; thus accurate compensation for the change in the illuminant is achieved.

It is important to note that the signal from the variable-gain amplifier is subtracted from the direct signal in order to form the error signal: the converse subtraction will give rise to a positive feedback condition.

In some circumstances it may be convenient to arrange the two variable-gain amplifiers shown in Fig. 1 so that the application of the same error signal gives rise to a gain change in one amplifier which is inversely proportional to that of the other. Since the required gain change of the amplifier in the video-signal path is always as given in Equation 7, the

other amplifier must in these circumstances be interposed between the reference photoreceptor (A in Fig. 1) and the subtractor circuit, photoreceptor B being directly connected.

The magnitudes of the photoreceptor signals E_A and E_B depend on the intensity of the illumination falling on the photoreceptors. For low illumination levels the approximations involved in the derivation of Equation 7 may not be satisfied and the amplifiers may assume incorrect gain values. The range of illumination intensity levels over which satisfactory operation is obtained may be increased by using an automatic gain control (a.g.c.) arrangement (the heavy lines in Fig. 2) in which identical variable-gain amplifiers in each photoreceptor signal path are controlled by an error signal formed by comparing the amplified photoreceptor signal in channel A (E'_A) with a fixed potential (E_{const}). One advantage of this system, rather than the use of the simpler arrangement shown in Fig. 1 with a suitably high value of the sensitivity factor $\mu_{E/E}$ (see Equation 5), is that the set of photoreceptors in the illuminant sensing head may in practice be a considerable distance from the camera control unit where the actual control of video-signal gain is carried out: the control signals from the illuminant sensing head may therefore require transmission by way of a long cable, in which case it is clearly desirable to avoid very low signal levels. Furthermore, if the a.g.c. arrangement operates in accordance with Equation 7, the gain of the a.g.c. variable-gain amplifiers is given by the factor E_{const}/E_A: thus

$$E'_A = E_{const}$$

$$\text{and } E'_B = E_{const} \cdot \frac{E_B}{E_A} \qquad (8)$$

where E'_A and E'_B are the signals leaving the a.g.c. amplifiers associated with photoreceptors A and B respectively. The magnitude of E'_B is therefore proportional to the ratio E_B/E_A irrespective of the absolute magnitude of these signals. This principle is used in generating the control signals in the prototype equipment* described in Section 3.

In a three-tube camera it is normal practice to use the green channel as the reference channel. The gain of the green channel is adjusted under standard lighting conditions and lens iris setting; the gains of the red and blue channels are then adjusted for correct colour balance. In a four-tube camera the luminance channel is similarly used as the reference. The variable-gain amplifiers required for automatic illuminant compensation should therefore be inserted in the red and blue channels of a three-tube camera and in all three colouring channels of a four-tube camera.

* although the method of obtaining a.g.c. action in this equipment is different (see Section 3.1.3).

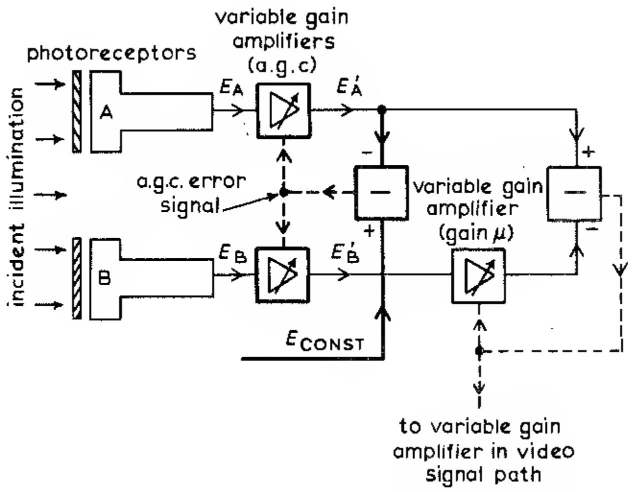

Fig. 2 - The provision of automatic gain control. (Components shown in thin lines also shown in Fig. 1)

The prototype equipment described in this Report was designed for use with a three-tube camera; this choice was made partly for simplicity (as only three photoreceptors are involved) and partly because three-tube cameras are at present extensively used in outside broadcast operations. It has been found in practice that the use of this equipment to correct the red and blue colouring channels of a four-tube camera, using the green colouring channel (not the luminance channel) as reference, gives very satisfactory results.

3. DESCRIPTION OF PROTOTYPE EQUIPMENT

3.1. The Illuminant Sensing Head

3.1.1. Polar Response of Head

A colour camera is normally balanced by observing a plane diffuse grey-scale chart placed orthogonally to the camera optical axis and exposed to the same illumination as the televised scene. The contribution to the total surface luminance of the chart from a discrete illuminating source is thus proportional to the source intensity and to the cosine of the angle of incidence** of the radiation on to the chart. The overall spectrum of light diffusely reflected by the chart is thus the integral of contributions from each such source. In an outside broadcast programme, in particular, the effective 'daylight' illuminant, as far as the colour balance of the camera is concerned, will be the result of such an integration process. In the automatic colour balancing system the illuminant sensing head must perform this same integration, and its orientation relative to the camera optical axis and polar response must both be appropriately chosen so that this operation can take place. In practice this means that the positioning of the illuminant sensing

**The angle between the direction of arrival of the radiation and the normal to the surface of the chart.

head should correspond with that of the grey-scale used in the manual adjustment of colour balance (that is, with its light-sensitive surface orthogonal to the camera optical axis). The appropriate polar response has in the prototype equipment been obtained by placing the photoreceptors behind a diffusing window (opal Perspex grade 040). In situations where a single camera is required to view scenes in widely different directions, and where the illuminant is markedly dependent on direction, several illuminant sensing heads (each facing a different direction) might be required, the appropriate head being selected by a switching arrangement. Alternatively, one illuminant sensor could sometimes be used which rotates with the camera, either by being mounted on the camera itself or on a remote servo-controlled turntable: the latter approach would be particularly suitable for use where the camera itself was remotely controlled.

3.1.2. Colour Sensitometric Considerations

The requirement for identity of spectral characteristic between each photoreceptor in the illuminant sensing head and the corresponding channel in the colour camera has been discussed in Section 1. The spectral characteristics of the colour separation channels of the three-tube camera for which the prototype equipment was designed are shown by the thin lines in Fig. 3, from which it can be seen that photoreceptor sensitivity over the wavelength range 400–650 nm is required. Consideration was first given to the use of silicon-based photovoltaic cells of small physical size and high nominal sensitivity: however, it was found that their sensitivity in the infra-red region posed a problem, as complete opacity to such radiation was required in the filters determining the spectral characteristics. Since such control of infra-red response is not easy to realize in practice, it was decided to use selenium barrier-layer photovoltaic cells in the prototype equipment: although of larger physical size than their silicon counterparts, their spectral

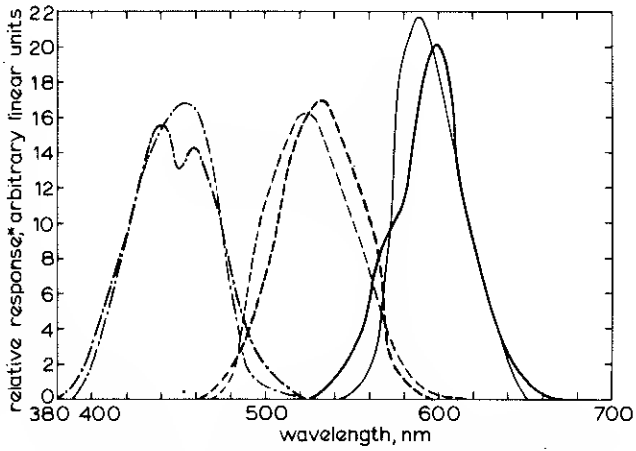

Fig. 3 - Spectral characteristics of three-tube camera (thin lines) and illuminant sensing head (thick lines).

* All curves normalized to equal area

response combines adequate sensitivity to blue light with almost complete insensitivity to infra-red radiation. The thick lines in Fig. 3 show the spectral characteristics obtained in the prototype equipment, calculated from the characteristics of the photoreceptors and colour filters: absorption-type filters were used throughout except for the determination of the long-wavelength flank of the red photoreceptor characteristic, where a dielectric filter was used. The results quoted in Section 4 were obtained using these characteristics.

3.1.3. Signal Processing

The output current of a selenium photoreceptor of the type discussed in Section 3.1.2., when operating into zero impedance, is linearly related to the intensity of the incident radiation and is independent of the ambient temperature. Operation of the photoreceptors under these conditions is obtained (Fig. 4) by the use of buffer amplifiers having zero impedance

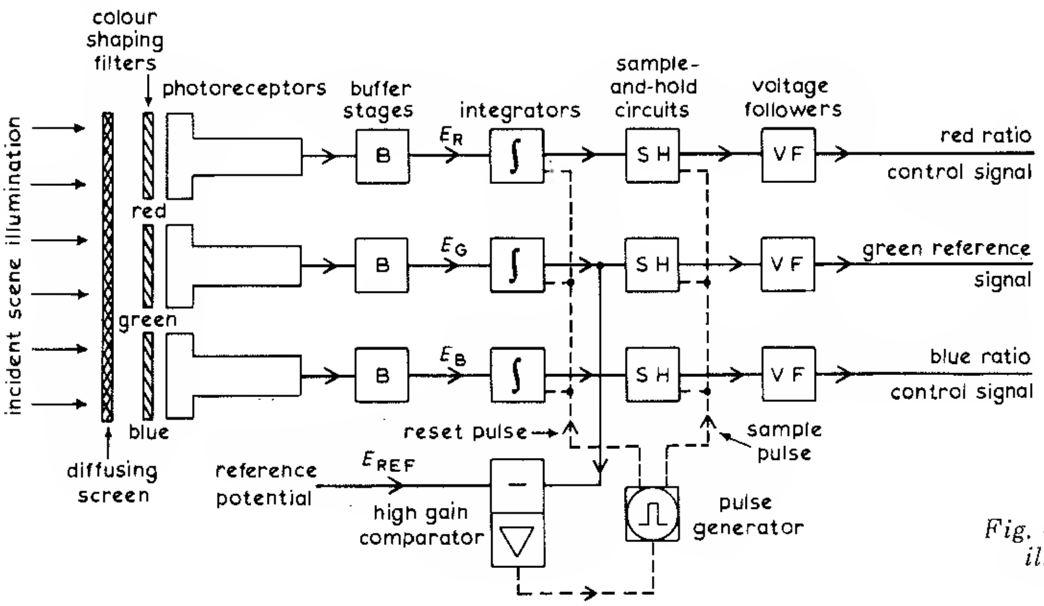

Fig. 4 - Circuit arrangement of illuminant sensing head

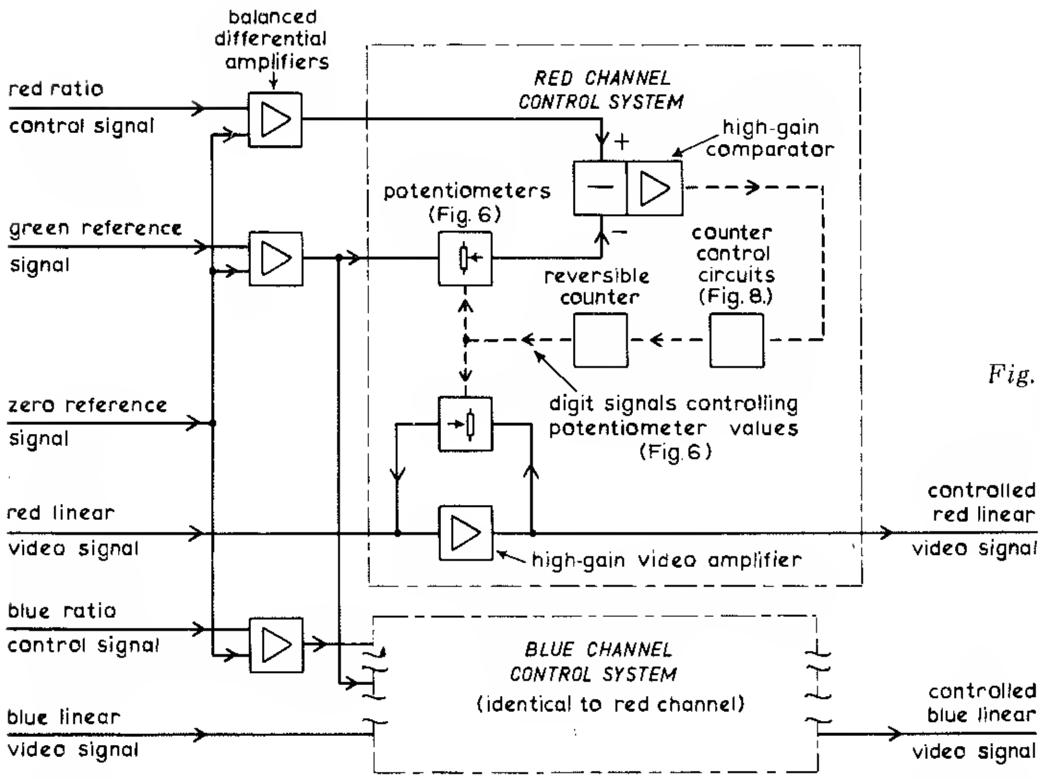

Fig. 5 - Principle of operation of control equipment

('virtual earth') inputs. The outputs of each of these amplifiers is a voltage whose magnitude is directly proportional to the intensity of the incident radiation falling on the appropriate photoreceptor.

Signals are required from the illuminant sensing head which define the ratios E_R/E_G and E_B/E_G, where E_R, E_G and E_B are the outputs of the buffer amplifiers connected to the red, green and blue photoreceptors respectively. In the prototype equipment the output of each buffer amplifier is connected to an integrator[2] whose output potential rises linearly at a rate proportional to the respective buffer amplifier output potential. When the integrator output in the green channel reaches a fixed reference potential (E_{ref}) a pulse is generated which is used to sample the output potentials of all three integrators: these potentials are stored in 'hold' circuits. Immediately following this sampling operation the integrators are 'reset' to zero potential: the cycle then recommences. The outputs of the hold circuits in the red and blue channels are signals which in principle have the values $(E_R.E_{ref})/E_G$ and $(E_B.E_{ref})/E_G$; as these signals are independent of the absolute magnitudes of E_R, E_G and E_B they are independent of the intensity of the illumination falling on the sensor head (this merely alters the repetition rate of the integrator charge/reset cycle described above). In practice this independence is not strictly obtained since, for constructional simplicity, the integration process is allowed to continue during the sampling operation. The outputs of the hold circuits in the red, green and blue channels may therefore be expressed as $(E_R/E_G*).E_{ref}$, $(E_G/E_G*).E_{ref}$ and $(E_B/E_G*).E_{ref}$ respectively, where the quantity E_G* nearly equals the value E_G, but departs from it slightly by an amount depending on the intensity of illumination. The red and blue hold-circuit potentials are passed by way of voltage-follower circuits to the video gain control equipment described in Section 3.2. and represent the 'ratio control signals': the green hold-circuit potential is similarly supplied to this equipment and forms the 'green reference signal,' thus compensating for the lack of independence from intensity of illumination.* This arrangement has the further advantage that resistive losses in the long multiway cable connecting the illuminant sensing head to the control equipment affect the two ratio control signals and the green reference signal to the same extent and are thus automatically compensated. D.C. power is also supplied to the illuminant sensing head by way of this cable, with the result that the control signals may be generated with respect to a potential different from the true zero ('earth') defined in the control equipment. A separate conductor in the cable, isolated from the power supply circuits, is therefore used to provide zero reference potential at the control equipment, against which the magnitudes of the control signals can be measured.

3.2. Control Equipment

3.2.1. Principle of Operation

Each of the three control signals generated in the illuminant sensing head is applied to one input of a balanced differential amplifier (Fig. 5), while the zero reference signal is applied to the other input.

* The ratio of the magnitude of the red ratio control signal to that of the green reference signal is termed the 'red correction ratio' in Section 4.1: the blue correction ratio is similarly defined.

These amplifiers have unity gain, so that the potentials at their outputs correspond to the magnitudes of the three control signals referred to the zero (earth) potential of the control equipment. The amplifiers present suitably high impedances to the sensing-head signals and the balanced input arrangements provide protection against common-mode signals induced into the cable connecting the sensing head and the control equipment; the effect of such signals is further reduced by the low-pass frequency characteristic of each amplifier.

Identical circuits are used to control the gains of the red and blue video channels: the control of the red video gain will be discussed with reference to Fig. 5. The magnitude of the red ratio control signal from the sensing head is arranged so that it never exceeds the green reference signal also derived in the sensing head. The green reference signal is supplied through a potentiometer chain to one input of a high-gain comparator, the other input of which is supplied directly with the red ratio signal. The output of the comparator, whose polarity indicates which of its two inputs is the greater, is used to control a reversible counter (see Section 3.2.2.); binary digit signals from this counter are used to adjust the attenuation inserted by the potentiometer chain until the two signals at the comparator input are equal. (This operation is more fully described in Section 3.2.2.). When this state is reached the output/input transmission coefficient of the attenuator will represent (apart from a normalizing factor) the ratio E_R / E_G where E_R and E_G are the red and green photoreceptor signals defined in Section 3.1.3. The output/input transmission coefficient required in the red video-signal path is (again excluding a normalizing factor) the ratio E_G/E_R (see Equation 7, Section 2): this condition is obtained by including an identical potentiometer chain, controlled by the same set of binary digit signals, in the feedback loop of a video amplifier with high forward gain. The gain normalizing factor is chosen so that the magnitude of the video signal leaving the video amplifier is compatible with the requirements of the following stages of the video processing chain; in the prototype equipment the amplifiers in both the red and blue video signals have unity gain when the illuminant sensing head is exposed to 'studio' illumination (having the spectral distribution of a total radiator at 3000K).

3.2.2. Control of the Reversible Binary Counter

Control of the attenuation introduced by a switched potentiometer chain, using a set of binary digit signals from a reversible counter,* is obtained by using the principle illustrated in Fig. 6. The resistor values forming the lower part of the chain are scaled so that the resistor associated with the digit of value 2^n has the value $\frac{R}{2^n}$ where R is the resistor value associated with the least significant digit. The effective resistance of this part of the chain will then have the value $\frac{R}{x}$, where x is the integer defined by the digit signals from the counter. The transmission coefficient of the attenuator, therefore, has the value

$$\frac{R}{R + xR_0}$$

(assuming that no current flows in the output circuit): thus a progressive increase or decrease of the attenuator transmission coefficient will result from a progressive decrease or increase of the integer value defined by the counter digit signals.

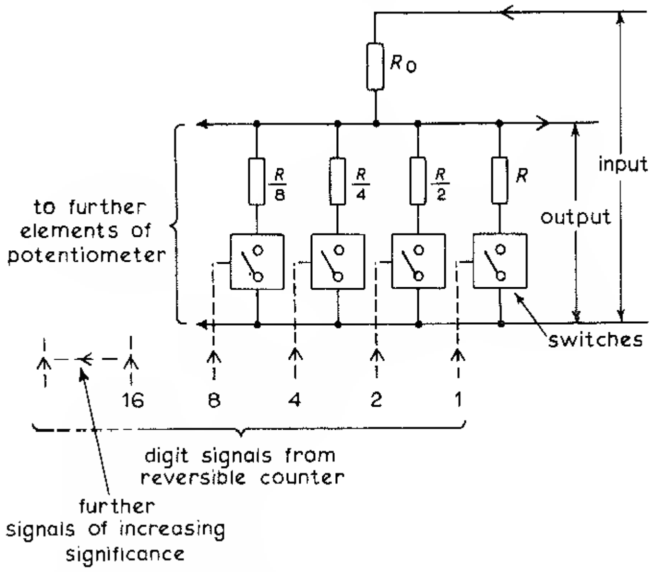

Fig. 6 - Principle of control of potentiometer by binary digit signals

In practice the reversible counter is driven by clock pulses (Fig. 7) having a period of 8 ms and obtained from a subsidiary counter driven by line drive pulses. The direction of count (forward or reverse) is determined by which of two logical states** is applied to a control wire, the required condition being generated by a director circuit (Fig. 8) which is in turn controlled by the output of the high-gain comparator. The director circuit can alter the control-wire state only on the arrival of a director clock pulse (Fig. 7): as this pulse does not coincide with a counter clock pulse, an unambiguous 'direction of count' command is available at the time of arrival of the next counter clock pulse.

As described so far, the control system described above would oscillate, at half the clock rate, between the two possible potentiometer values on either side of the true value required for exact equality of

* In the prototype equipment an eight-bit counter is used.

** In the logic elements used in the prototype equipment, the state '1' corresponds to a positive potential relative to earth, while '0' corresponds to earth potential.

the comparator input signals. This instability is prevented by using a further pulse (the 'peep' pulse in Fig. 7) to add another resistor R_p, of value slightly less than R, to the potentiometer chain in the green reference signal path (Fig. 9). If the comparator reacts to this pulse (indicating that the nearest possible potentiometer value on the high side of the true value has been reached), the proximity detector (Fig. 8) suppresses the following counter clock pulse by closing a gate in this clock-pulse path; this prevents the counter from operating. After the occurrence of this clock pulse, but before the occurrence of the next peep pulse, the proximity detector is reset* so that the counter clock pulse gate is opened again. This cycle of events occurs every time the comparator reacts to the peep pulse. The proximity detector can only function if the 'proximity enable' pulse (Fig. 7) is present: thus signals at the output of the comparator other than those produced by reaction to the peep pulse cannot inhibit the operation of the counter. The peep pulse arrangement is not included in the potentiometer controlling the video signal.

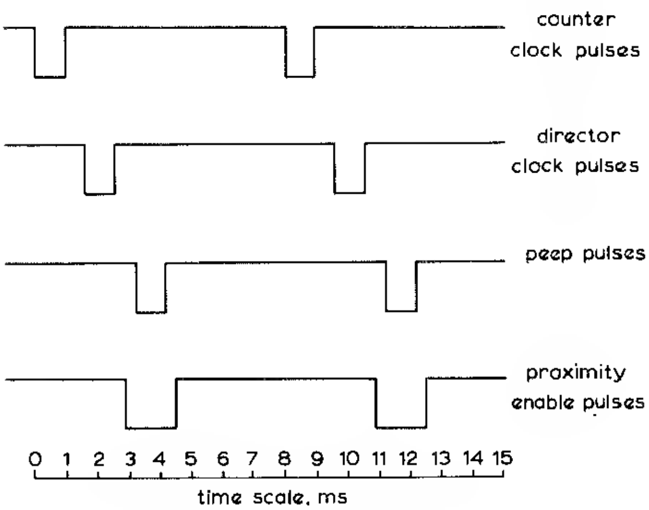

Fig. 7 - Pulses used in the reversible counter control system

Conditions may occur in which the potentiometer value required for equality of the comparator input signals is outside the range of the potentiometer and reversible counter. Under such conditions the control system described above will be ineffective and the counter will operate continuously. A continually increasing or decreasing count value will be produced (depending on whether the out-of-range condition causes a forward or reverse count), the occurrence of one extreme count value being immediately followed by the production of a 'carry' digit and a jump to the other extreme count value. This operating condition will give rise to a cyclical variation in the gain of the associated video amplifier: it is prevented by using the carry digit to close the clock-pulse gate

* The director clock pulses are used for this purpose.

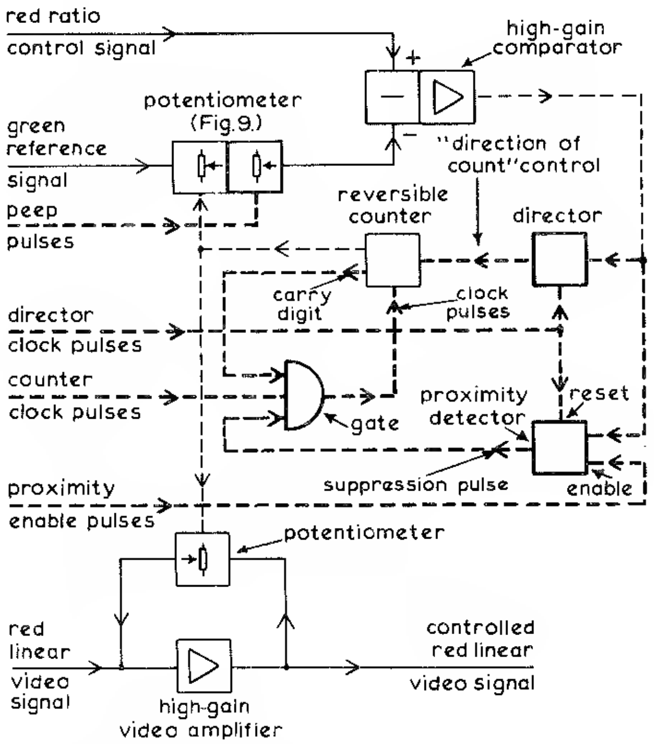

Fig. 8 - Counter control circuits (red channel illustrated). (Components shown in thin lines also shown in Fig. 5)

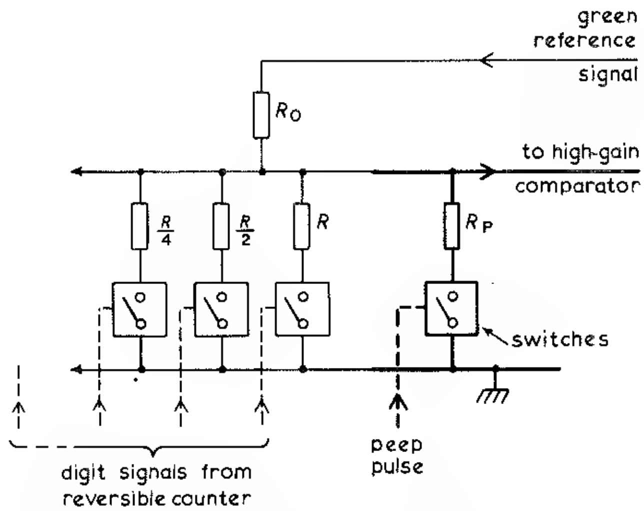

Fig. 9 - Addition of peep pulse facility to potentiometer chain. (Components shown in thin lines also shown in Fig. 6)

(Fig. 8) and thus stop the count at one or other of its extremities. Correct colour balance compensation will clearly not be obtained if the change in illuminant is so great as to give rise to such 'out of range' operating conditions and the carry digit is therefore arranged to give a visual indication that this condition has been reached.

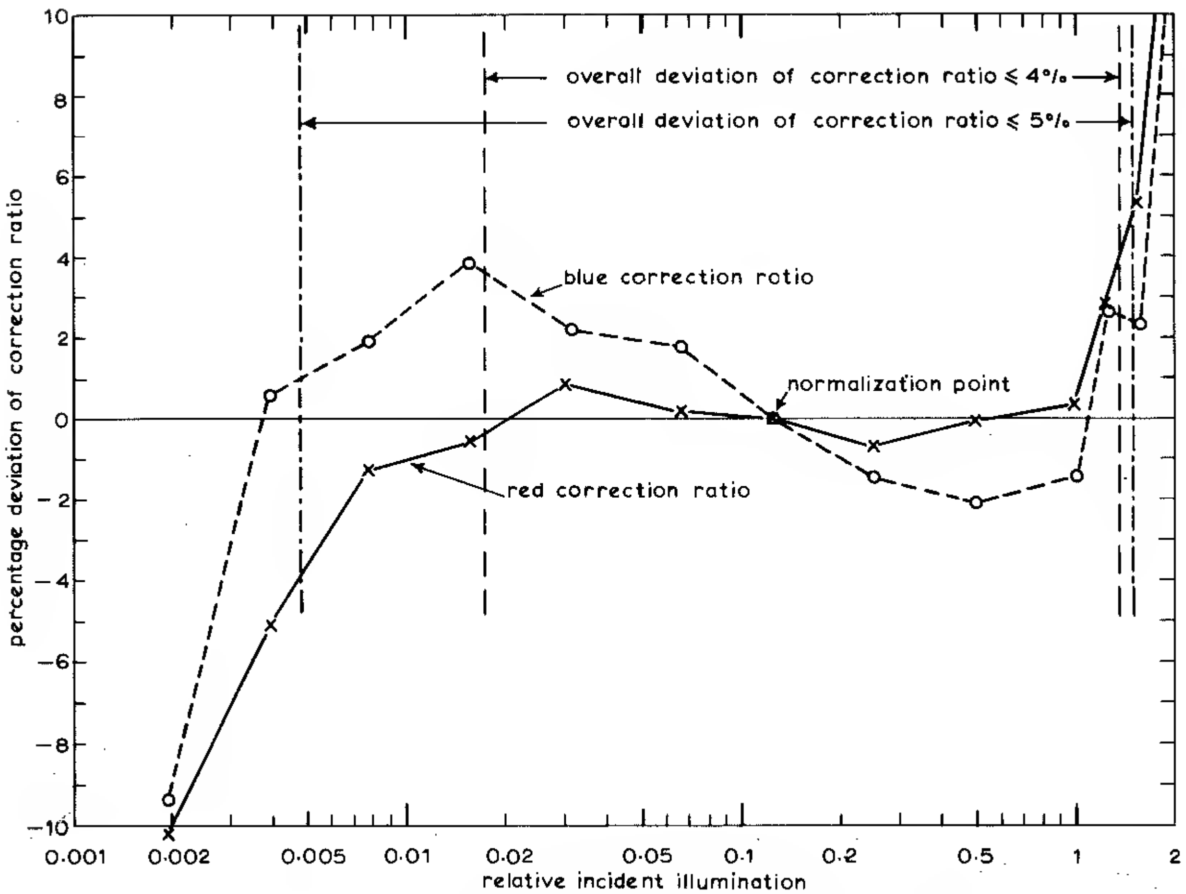

Fig. 10 - The effect of variations in the intensity of the incident illumination

4. THE PERFORMANCE OF THE PROTOTYPE EQUIPMENT

4.1. The Effect of Change of Illumination Intensity

Change of intensity of the illuminant incident onto the sensing head was obtained without alteration of its spectrum by varying the distance between the sensing head window and the source of illumination. The resulting changes in the red and blue correction ratios (these quantities are specified in the footnote on page 5) are shown in Fig. 10 for the case in which the illuminant corresponded to standard studio lighting. The change in each correction ratio is expressed in terms of percentage deviations from a normalized value corresponding approximately to the mid-point* of the illumination intensity range over which correct operation is obtained. It can be seen that the error in correction ratio between any two channels is less than 4% over a range of illumination intensities of about 80:1 and less than 5% over a range of about 300:1. As a small error in the correction ratio will give rise to the same error (but of the opposite sign) in the balance ratio (this quantity is defined in Section 4.3.1) corresponding changes in the overall linear video-signal balance will be obtained for these illumination intensity changes.

Changes in linear video-signal balance of 4% do not produce any noticeable colorimetric errors in the displayed picture,[3] while colorimetric errors will remain very small for balance errors of 5% (for instance, the subjective assessment of colour rendition shown in Fig. 13 (Section 4.3.2) may be compared with the corresponding measured balance ratios (Fig. 12, Section 4.3.1)). The range of illumination intensities over which the prototype equipment operates satisfactorily is therefore considered wide enough to enable its ability to maintain a camera in correct colour balance to be assessed, although too restricted to include the full range of intensity values (see Section 1) that may be encountered in practice. It may however be noted that the lower 5% limit shown in Fig. 10 corresponded to an actual intensity of 4 ft C (43 lux): the equipment is therefore capable of operating under low intensity lighting conditions.** For use under lighting conditions of high intensity the light entering the sensing head may be attenuated using a neutral filter or aperture plate. Under these conditions satisfactory operation may be obtained over a range of illuminant intensities including full sunlight and normal studio lighting (150 ft C or 1600 lux).

* in logarithmic units

** although tests under operational conditions indicate that greater sensitivity is required.

Small currents will be present at the inputs of the buffer amplifiers (Fig. 4) in the complete absence of photoreceptor illumination. These currents are due partly to photoreceptor 'dark current' and partly to imperfect balance of the input stages of each buffer amplifier. In the prototype equipment these currents are balanced out as far as possible: the failure of the equipment to operate correctly in low illuminant intensities occurs when the residual dark currents become significant. No attempt has been made in the prototype equipment to allow for the known dependence of dark current on temperature, and the performance under low intensity lighting conditions may therefore be impaired by a change in photoreceptor temperature (due to exposure of the sensing head to sunlight, for example) after the balance adjustment has been made. The cessation of correct operation for high illumination intensities is caused by overloading of the buffer amplifiers.

4.2. The Generation of Test Illuminants

The operation of a camera in differing scene illuminants can be simulated by placing, in turn, a selection of colour filters over the camera lens. The set of filters used in the objective measurements and subjective assessments described in the following two sections are shown in Table 1. During these tests the camera was operated under studio lighting conditions (i.e. the basic scene illuminant corresponded to a total radiator at 3000K): the chromaticities of the effective illuminants obtained by the use of the filters under these conditions are shown in Fig. 11.

TABLE 1

Test Filters

Test Condition	Filter(s)
A	Kodak CC20Y
B	Wratten 82C
C	Kodak CC20M
D	Wratten 78A
E	Wratten 78AA
F	Wrattens 82C and 78AA

4.3. The Effect of Change of Illuminant

4.3.1. Objective Measurements

The measured effects of the spectrum changes, obtained by using the set of test filters specified in Section 4.2, on the video-signal balance of a three-tube camera are shown in Fig. 12 (full triangles). The measurements are expressed in terms of the red and blue 'balance ratios' (the ratios of the red and blue linear video-signal levels derived from a neutral grey-scale to, in each case, the corresponding green linear signal level). The signal-channel gains were initially adjusted for equality of the video signals with no filter placed over the camera lens. Good agreement was obtained between the measured values and those calculated (full squares in Fig. 12) from the analysis characteristics of the camera and the effective scene illuminants.

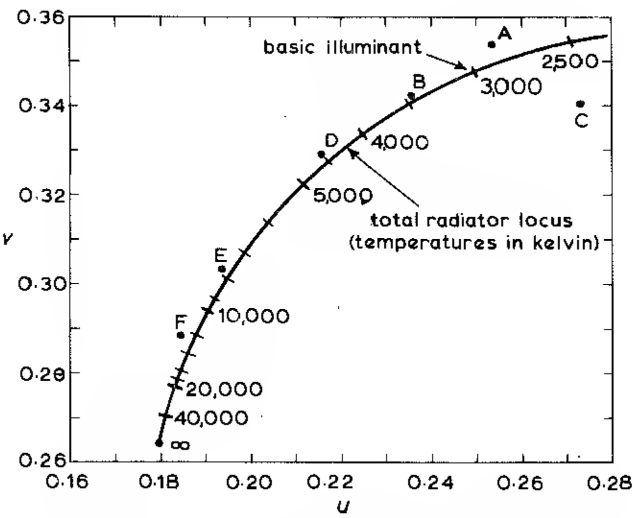

Fig. 11 - Illuminant chromaticities obtained by use of test filters (see Table 1)

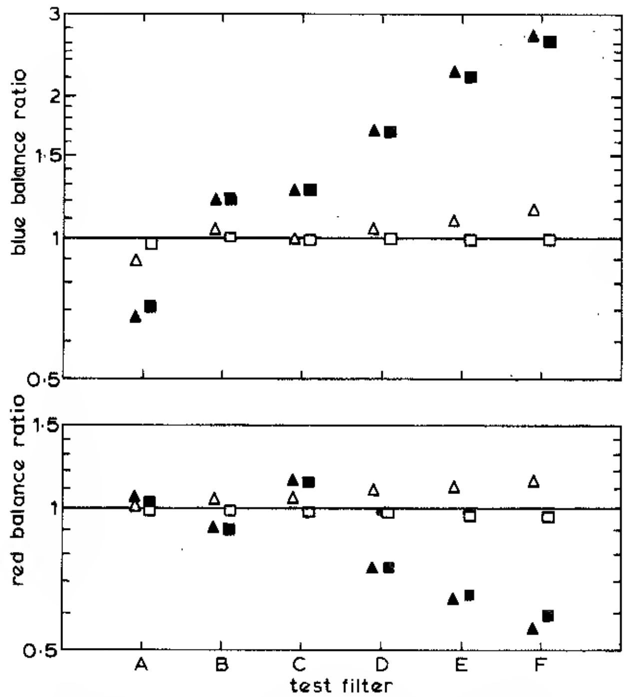

Fig. 12 - Measured and calculated balance ratios

	Symbol Key	Measured	Calculated
Position of Colour Filters	Camera Lens Only	▲	■
	Camera Lens and Sensing Head	△	□

For the measurement of the effectiveness of the prototype equipment in compensating for changes in the illuminant, the illuminant sensing head was placed adjacent to the grey scale so that its diffusing window and the grey scale were co-planar, and identical colour filters were then placed over both the camera lens and the sensing-head window. The calculated and measured balance ratios obtained under these conditions are shown by open squares and open triangles respectively in Fig. 12. The degree of correction obtained in practice was rather less in the blue channel and rather greater in the red channel than the very accurate values expected from the calculations. These discrepancies are probably due to slight departures of the actual spectral characteristics of the illuminant sensing head from the values shown in Fig. 3 and do not invalidate the conclusion that effective compensation is obtained for changes in the illuminant.

It is worth noting that for correct operation of the equipment the change of gain in the linear video-signal path must not be accompanied by a change in the d.c. potential corresponding to black level. Such a black-level shift will be produced if the pulse-cancelling adjustments* in each channel of the camera are incorrect and care must therefore be taken that these adjustments are correctly made. For the same reason it is not possible to use the pulse-cancelling adjustment as a method of varying the black-level potential.

4.3.2. Subjective Assessments

A group of seven observers, familiar with the viewing of colour television displays, was presented with each of the test conditions described in Section 4.3.1 and asked to assess the impairment of the picture due to incorrect colour rendition, using the subjective scale shown in Table 2. The scene used during the test contained facial skin tones, highly-saturated colours and neutral areas. The camera was provided with a linear-signal matrix[4] and was exposed so that the greatest of the three colour-separation signals reached peak level. Included in the test were 'standard' conditions in which no colour filter was placed over the camera lens or the sensing-head window: the observers were shown a picture under these standard conditions before the start of the tests but were not told when they were repeated during the tests themselves. Viewing was carried out in subdued lighting having approximately the same chromaticity as the colour-display white point, the viewing distance being about eight times the picture height.

The mean grade obtained from each test condition is shown in Fig. 13, together with a significance limit equal to twice the standard error* of the assessed grade values. The occurrence of a mean grade value greater than unity for the standard conditions was probably caused by incomplete colour adaptation of the observers to the nominal white point of the display, after viewing test conditions in which a very pronounced colour cast was introduced. The three mean grade values lower than the reference value may also be attributed to this cause; in any case the difference between each of these grade values and that for the standard conditions is not statistically significant. In each test condition a significant reduction in impairment was introduced by the operation of the prototype equipment, the mean grade values being reduced in all cases from values representing degrees of objectionability to values representing degrees of perceptibility.

TABLE 2

Scale of Impairment

Grade	Impairment
1	Imperceptible
2	Just perceptible
3	Definitely perceptible but not disturbing
4	Somewhat objectionable
5	Definitely objectionable
6	Unusable

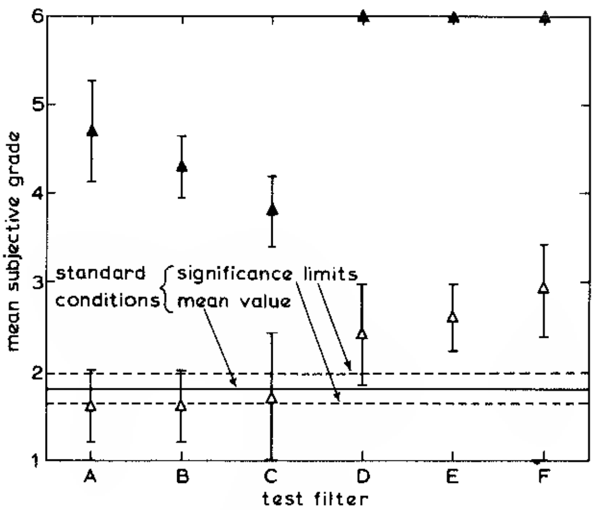

Fig. 13 - Results of Subjective Tests

Symbol Key

Position of Colour Filters	Camera Lens Only	▲
	Camera Lens and Sensing Head	Δ

* Adjustments for offsetting the spurious pulses produced during the line flyback interval by induction from the line-scan coils, so that these pulses do not perturb the operation of subsequent clamping circuits.

* For a Gaussian distribution the probability that the mean value would fall outside this significance limit, if the experiment were to be repeated, is 0·05.

5. DISCUSSION OF TECHNIQUES NOT INCORPORATED IN PROTOTYPE EQUIPMENT

5.1. The Sensing Head

The three photoreceptors in the prototype equipment are placed side-by-side behind the diffusing window (Section 3.1.1). Uneven illumination of this window affects the relative outputs of the photoreceptors and gives rise to errors in the control-signal magnitudes. An optical system not prone to such errors is clearly required for operational use. A dichroic colour-splitting system similar to the arrangement used in a conventional colour camera would permit light from the same area of the diffusing window to fall on all three photoreceptors, and would therefore provide the required immunity from such errors.

As the sensing head might occasionally be visible in the transmitted picture it would seem important to reduce its physical size as far as possible. At the same time it must be able to withstand severe climatic conditions as its use would often require it to be placed in an exposed (and possibly relatively inaccessible) position for long periods. For this reason it is important to ensure that extremes of temperature do not cause errors in the control-signal magnitudes (see Section 4.1). The correct operation of the sensing head over the full range of incident illumination intensities must also be achievable without the need for manual adjustment of the head during operational use. An automatic or remotely-controlled shutter or iris arrangement could be used, although this would add to the size and complexity of the head. It may however be noted that the photoreceptors used in the prototype equipment are capable of operating over the full illumination intensity range, the restricted range evident in this equipment being caused by the overloading of the buffer amplifiers following the photoreceptors (see Fig. 4 and Section 4.1). These buffer amplifiers were included because the action of resetting the integrator circuits (Fig. 4) was found to affect the operation of the photoreceptors when these were directly connected. If alternative integrator resetting circuits were to be developed which did not affect the operation of the photoreceptors, the buffer amplifiers would no longer be required and the dynamic range of the equipment consequently improved.

Although reasonable similarity was obtained between the spectral characteristics of the camera and the illuminant sensing head, the differences between them (see Fig. 3) could, in the presence of line spectra as produced by some discharge lamps, give rise to greater errors in performance than the results quoted in Sections 4.3.1 and 4.3.2. It is considered that a closer match between the two sets of spectral characteristics should be provided in operational equipment.

5.2. Connection of Sensing Head and Control Unit

The provision of special multiway cables for the interconnection of the illuminant sensing head and control unit is likely to be inconvenient in Outside Broadcast use. A better method would be to use a type of cable (and connector) already extensively used. Conventional microphone cable offers two conductors and an earth return, and would therefore be suitable for supplying d.c. power to the sensing head and transmitting the control signals from the head (the red and blue ratio signals, green reference signal and zero reference potential discussed in Section 4.1.3) using a time or frequency-division-multiplex technique.

5.3. Use of Single Variable-gain Amplifier in Control Equipment

The prototype equipment uses separate variable-gain amplifiers for detecting the magnitudes of the sensing-head signals and for actually controlling the video-circuit gain. Both of these functions may be performed by a single amplifier by adding a control pulse to the linear video signal whose height is proportional to the ratio E_R/E_G or E_B/E_G (see Section 3.1.3) and passing this composite signal through the amplifier. The amplifier gain is controlled by an a.g.c. arrangement that maintains a constant control-pulse height at the output of the amplifier.* The control pulse must be arranged so that it does not interfere with clamping operations in the subsequent signal-processing circuits and should be suppressed before the signal leaves the camera control unit.

6. CONCLUSIONS

Prototype equipment has been developed which provides automatic re-adjustment of the video-signal balance of a colour camera in the presence of changes in the scene illuminant. The degree of correction achieved in the presence of relatively broad-band spectra is such that a balance error greater than 260% (i.e. an erroneous signal level of some 2·6 times the correct value) is reduced to an error of 15%. Subjectively this corresponds to a reduction in picture impairment from Grade 6 (impairment renders the picture unusable) to Grade 3 (impairment definitely perceptible but not disturbing). Correspondingly smaller residual errors are present if the degree of unbalance is less than this extreme case.

* Allowance can be made for inaccuracies in ratio control-signal magnitude (and therefore in added-pulse heights), as discussed in Section 3.1.3, by using the green reference signal as the pulse-height datum in the amplifier a.g.c. arrangement.

As it stands the prototype equipment is not ideally suited to operational use. The illuminant sensing head should be smaller, should have greater immunity from the effect of temperature changes and should be capable of operating in a wider range of illumination intensities: in addition, the degree of similarity between the spectral characteristics of the camera and the sensing head should be closer. Changes are also desirable in the method of interconnection between the sensing head and the control unit.

7. REFERENCES

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